N86-11445

OVERVIEW OF SOLID PARTICLE LV SEEDING TECHNIQUES USED AT UTRC

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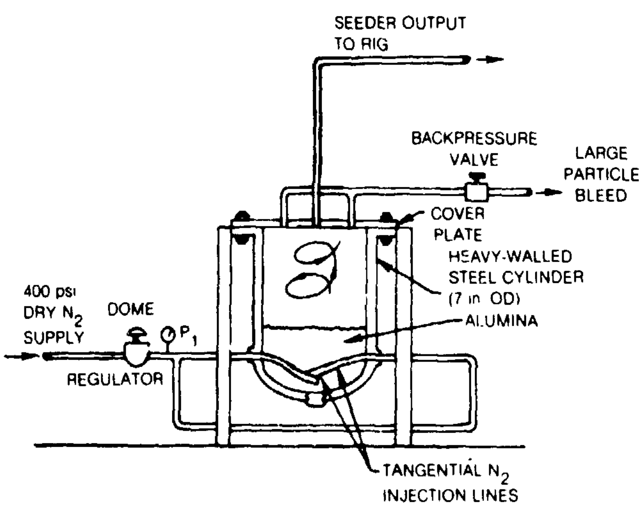
PERFORMANCE OF ORIGINAL FLUIDIZED BED SEEDER

The original solid particle seeder (fig. 1) consisted of a thick-walled steel cylinder (18 cm dia x 15 cm long) which was closed by a welded hemispherical cap at one end and a bolted cover plate at the other. Copper tubes (.48 cm ID) aligned tangentially along the cylinder walls near its base were used to inject dry nitrogen into the seed powder to agitate the seed and to induce a swirling flow above the seed bed. Large seed particles (or agglomerates) entrained in the swirling flow were transported toward the outer wall by centrifugal force where they were bled off by two ports in the cover plate. The remaining seeded nitrogen was ducted to the rig.

The seeder was charged with 0.3μm dia alumina particles (CR-type agglomerate free). Although the powder is free of large agglomerates, it consists of naturally occurring 3μm aggregates (ref. 1) which must be broken down by vigorous action within the seeder. The measured particle size distributions produced by the original seeder are also shown in figure 1. At low pressure operation (30 psig.) 77 percent of the measured particles were in the submicron range (0.3 - 1.0μm). At 50 psig. and 100 psig. the percentage of submicron particles deteriorated to 36 percent and 15 percent, respectively.



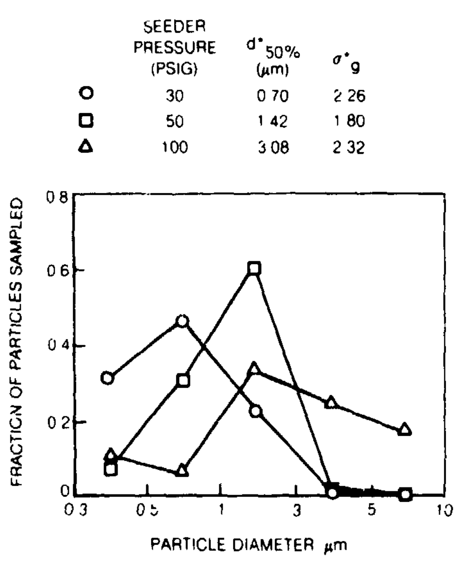


Figure I

DESCRIPTION OF FLUIDIZED BED SEEDER WITH VORTEX SEPARATOR

Due to the failure of existing seeders to meet the stringent specifications required for benchmark experiments in high pressure, high temperature, rapidly accelerating flowfields, an effort was made to improve the existing solid particle seeder (ref. 2). The goal was to produce a more monodisperse seed from the 0.3μm alumina powder with more than 99 percent of the particles in the submicron range while maintaining a high seeding rate. The modified seeder is shown in figure 2.

Coiled-wire inserts were installed within the ends of the nitrogen injection lines in the primary seeder to produce swirling conical jets to vigorously agitate the seed bed. A secondary swirler, constructed from a 25 cm length of 3.8 cm ID steel pipe having threaded end caps, was connected to the output line of the primary seeder. The seeded nitrogen from the primary seeder was injected tangentially at near sonic velocity into the secondary swirler 9.4 cm above its base. Independently controlled auxiliary nitrogen used to increase the swirl in the secondary chamber was also injected tangentially 2.5 cm below the seeded nitrogen lines. Large seed particles were collected by bleeds in the swirler cap and directed overboard. The remaining seeded nitrogen was collected on the centerline of the secondary swirler and ducted to the rig.

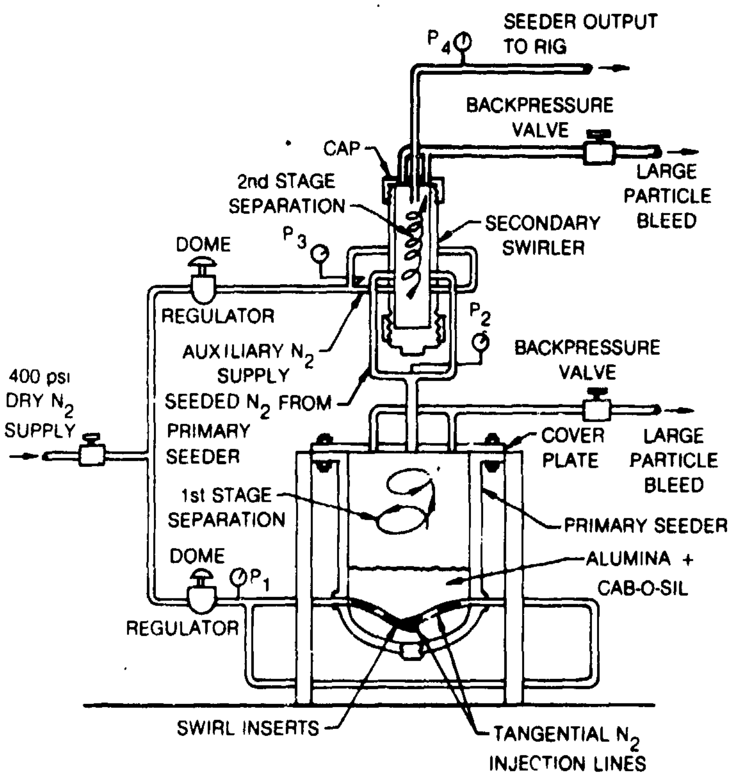


Figure 2

PERFORMANCE OF FLUIDIZED BED SEEDER WITH VORTEX SEPARATOR

Isokinetic particle sampling in a calibration jet seeded with 0.3 μm alumina powder was performed to determine the effectiveness of the seeder modifications shown in figure 2. In the first series of tests the modified seeder was operated with a passive secondary swirler. The auxiliary nitrogen supply was not activated for these tests. The results for low pressure operation are shown in figure 3.

At 30 psig operating pressure, the seeder exceeded the required specifications. More than 88 percent of the measured seed particles were in the 0.3 μm range, 11 percent were in the 0.5 μm - 1 μm range, the mean particle diameter was 0.413 μm and the standard deviation, δ_g^*, was 1.19, indicating a monodisperse seed distribution. At 50 psig, the distribution remained satisfactory with only 1.5 percent of the particles being larger than 1 μm. At 100 psig the distribution deteriorated badly; the median diameter increasing to 0.742 μm and 25 percent of the particles were larger than 1 μm.

A second series of tests demonstrated the effectiveness of the auxiliary nitrogen supply in optimizing the seed distribution at higher pressure operation. Figure 3 shows the optimized particle distributions obtained from three tests at 140 psig. As indicated in the figure, the seed particle distribution was monodisperse with almost 90 percent of the measured particles in the 0.3 - 0.5 μm range and only 0.7 percent greater than 1 μm. The median particle size was 0.41 μm. An estimate of seed generation rate was obtained by multiplying the counting rate of the particle analyzer by the ratio of the calibration jet area to the capture area of the isokinetic sampling probe. This resulted in excess of 10^{10} particles/min.

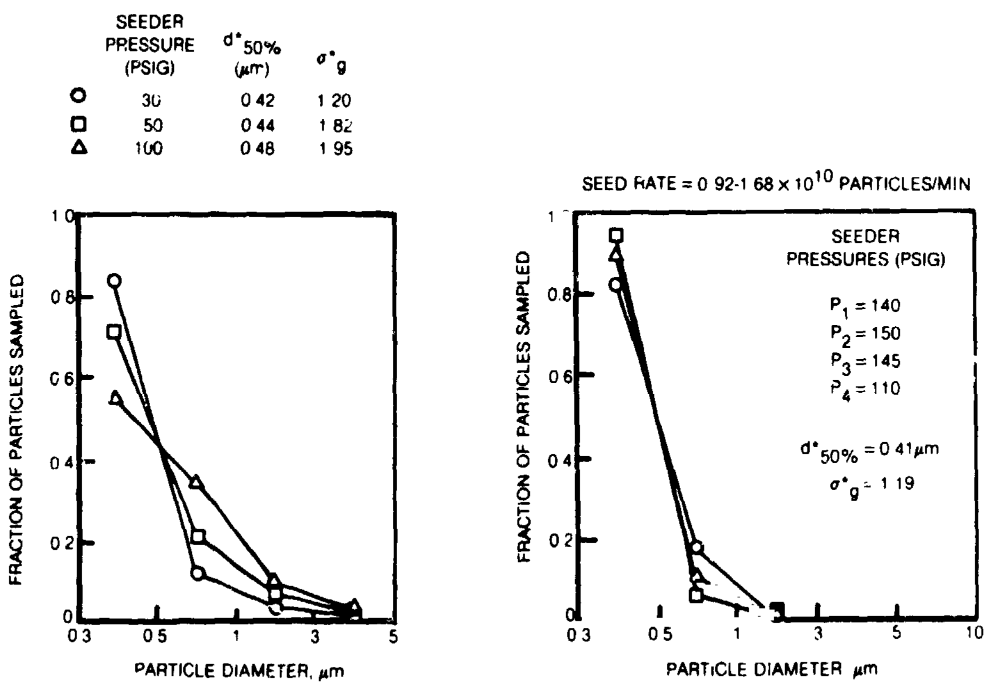


Figure 3

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LV MEASUREMENTS IN HIGHLY ACCELERATED TRANSONIC MODEL FAN DUCT EXHAUST

LV measurements were made in the exit plane of a model turbofan engine fan duct shown in figure 4. Operating at a pressure ratio of 2.5, flow within the fan duct was subsonic up to the throat (located just upstream of the exit plane) and mixed supersonic-subsonic in the exit plane. Strong acceleration fields existed just upstream of the exit and in the downstream exhaust flowfield which was bounded on the inner side by the simulated engine afterbody. LV measurements in the fan duct exit plane are shown in figure 4. The original seeder produced a distribution with a maximum Mach number of 1.0 even though the nozzle was operated at a pressure ratio of 2.5 and the exit plane was located downstream of the choked throat. When the modified seeder was used with an active vortex separator, the measured flow showed the desired supersonic-subsonic velocity profile. Accelerations on the order of 7600 m/sec/m were measured at one radial position in the immediate vicinity of the fan duct exit.

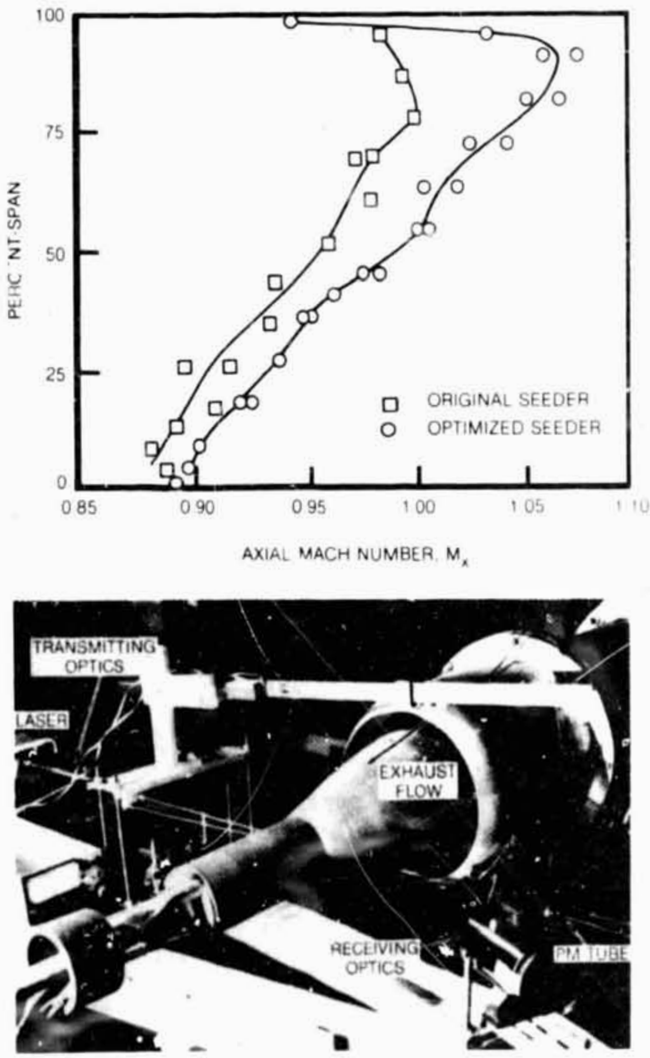

Figure 4

LV MEASUREMENTS THROUGH A NORMAL SHOCK WAVE

Direct measurements of the velocity lag characteristics of seed particles encountering a normal shock have been made at UTRC. The measurements were made in a supersonic wind tunnel test section designed for the study of shock-boundary layer interactions (fig. 5). The seeded air was accelerated to M = 1.4 before encountering the normal shock. LV measurements taken on the wind tunnel centerline are shown in figure 5 for two seed materials, 30 μm dia glass microballoons and 0.3 μm dia alumina.

The 30 μm dia hollow glass microballoons were reputed to have been capable of following extreme flowfield gradients. The velocities measured in the vicinity of the shock wave, however, showed that the microballoons not only barely responded to the step change in flow speed across the shock but they also lagged the flow by 15 percent upstream of the shock. The 0.3 μm dia alumina particles generated in the fluidized bed seeder with the vortex swirler activated followed the flow through the shock with minimal error. The alumina particles decelerated at the rate of 20,00[illegible] sec/m through the shock. Just downstream of the shock (x = .25 cm) [illegible] velocity determined from the peak in the histogram of measured samples [illegible] m/sec lower than the histogram average. This phenomenon occurred because the subsonic flow on the wind tunnel centerline accelerated for a short distance downstream of the shock due to the contraction in the aerodynamic cross-section caused by the separated boundary layer. Since the velocity at x = .25 cm represented a local minimum, shock wave jitter caused the histogram to be skewed toward higher velocities resulting in the histogram average being substantially larger than the velocity at the histogram peak.

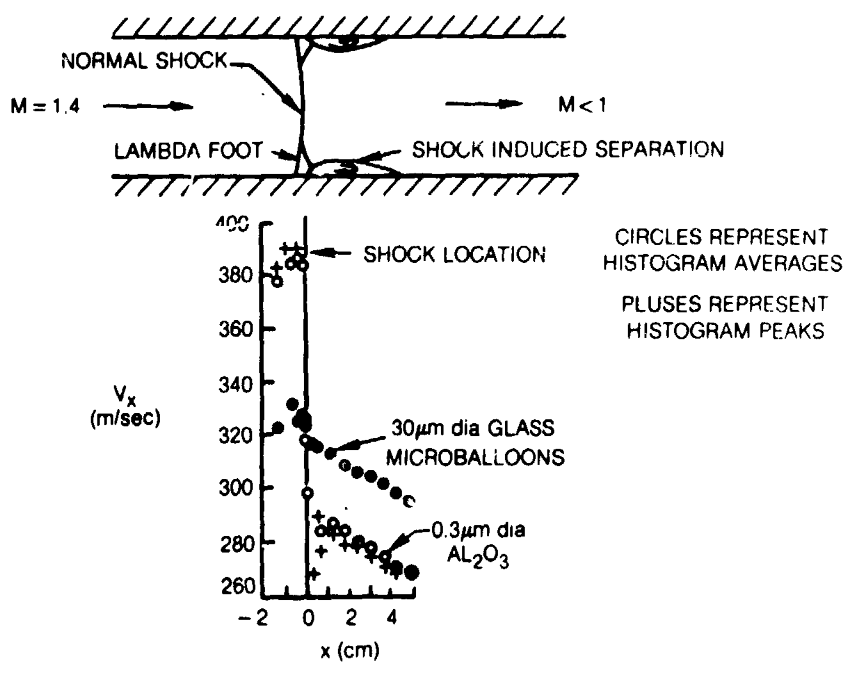

Figure 5

ZERO-WAKE SEEDING PROBE

A cylindrical seeder probe, shown in figure 6, has been designed at UTRC to effectively seed the flow while minimizing the disturbances to the wind tunnel airstream. A similarly configured probe designated the "zero-wake seeder" has been developed independently by Simpson (ref. 3). In principle, the flowrate through the seeding probe is adjusted until the momentum of the seeded air injected into the base region of the cylinder equals the cylinder drag and eliminates the wake deficit.

The zero-wake seeding probe has been used successfully to seed the flow field in a recently completed subsonic separated turbulent boundary layer separation bubble experiment at UTRC (ref. 4). The seed was injected into the wind tunnel plenum upstream of a 4 to 1 tunnel contraction. The seeding probe produced a seed cloud having an approximately circular cross-section with a 15 cm dia at the test section inlet 500 probe diameters downstream. Total pressure probing revealed no discernible wake deficit at the test section inlet during seeder operation. Similarly, hot-film measurements showed no difference in freestream turbulence level at the test section inlet during seeder operation compared to the clean tunnel operation with the seeder probe out of the tunnel. As expected, the turbulence level was increased when the probe was in the flow but not operating.

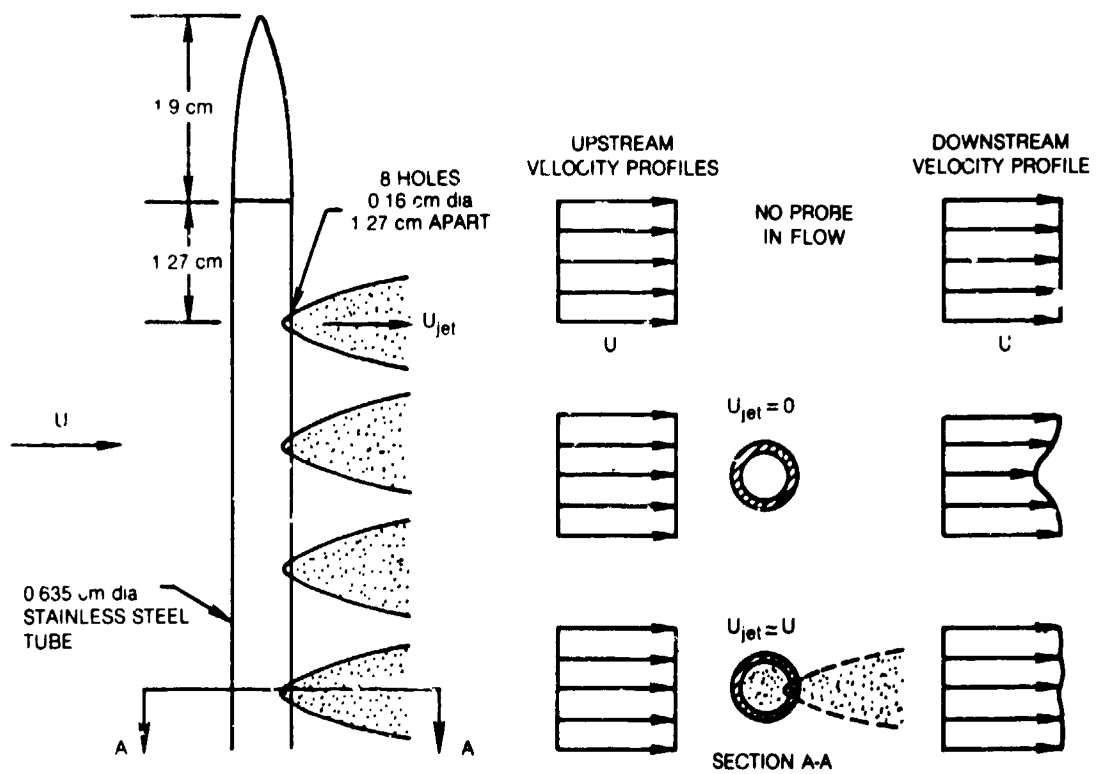

Figure 6

D. C. McCormick of UTRC has developed the incense seeder, shown schematically in figure 7, to generate submicron seed particles. The measured size distribution of seed generated by the seeder from No. 2 Gonesh incense cones* is also shown. All the measured particles were submicron with 90 percent of the particles being in the 0.10-0.45μm dia. range. The incense seeder was used to seed the flow in a model turbofan engine fanduct exhaust which was half the scale of the model shown in figure 4. The acceleration field within the model fanduct was estimated from wall static pressure measurements. Maximum velocity lag in the accelerating flowfield for incense seed having the particle size distribution measured above was estimated to be 1.25 percent, and occurred just downstream of the model throat where the acceleration approximated 30,000 m/sec/m. Additional calculations showed that the incense seed would achieve 99 percent of the step change in velocity across an idealized M=1.4 normal shock within 1 mm of the shock front. The accuracy of LV mean velocity measurements subsequently made in the afterbody flowfield was verified by comparing the measured velocities to the velocities determined from pitot measurements and Rankine-Hugoniot shock relationships at selected locations. The advantages of the incense seeder are its submicron size distribution which produces minimal rig contamination and its simple operation. Disadvantages are that the seed particles cannot be seen in backscatter and the incense cones burn out in 10 minutes.

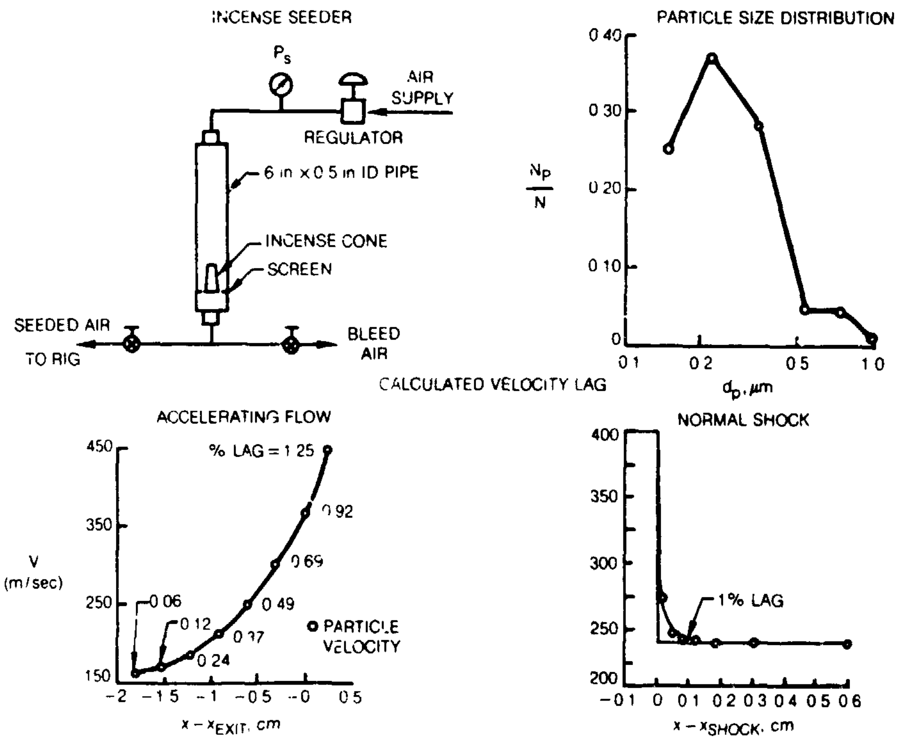

Figure 7

*Gonesh Incense, 200 North Lafl[illegible] St., Chicago, IL 60607

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